OPTIMAL MANAGEMENT OF RESEARCH PROJECTS IN THE NOT-FOR-PROFIT SECTOR

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Consider a not-for-profit research and development (R&D) organization such as an academically affiliated hospital. In addition to providing the full range of clinical services, the hospital staff typically engages in a wide range of scientific research and development. In recent years, most not-for-profits have set up an office of technology transfer to handle those R&D projects which may potentially have commercial value. In fact, in the current environment in which medical reimbursement rates to hospitals have fallen and traditional sources of research grants have dried up, most not-for-profits view the technology transfer office as a potential "profit" center for the institution. As a consequence, the objective function of the technology transfer office is to monetize its R&D projects in an optimal way.

A typical R&D project sequence is as follows. A scientist (typically a staff M.D. referred to as a Principal Investigator, i.e., P.I.) approaches the hospital for funding to take a research idea to the laboratory. This initial funding would be used for laboratory space, equipment and supplies, initial animal testing, and to cover some part of the P.I.'s salary. Naturally, the P.I. will also look external to the hospital for funding, but we will concentrate on funding which comes directly from the hospital. Through time, the scope and size of the project expands as the P.I. requires testing in larger (and more expensive) animal models, requires larger sample sizes to evaluate statistical significance, and faces significant costs for patent prosecution, etc. At some point, the hospital will decide it is no longer appropriate to self-fund the project, but rather to sell (license) the technology to a third party and ask this third party to both fund and take operational control of the project. The third party is usually an entrepreneur who will seek funding or an established pharmaceutical firm.

We would like to study questions of the following sort. What is the appropriate level of funding by the hospital? Does it make sense for the hospital to partially develop the technology and then sell it? If so, at what point in the development process is it "optimal" to sell the technology?

Clearly the hospital wishes to maximize the net present value (NPV) of the R&D project. It has as control variables the amount of funding that it will provide and the point in time at which it will sell the technology. Following Myers and Howe (1997), we will not implement an options-based methodology at this point. At this very early stage R&D, options to continue research will almost surely be exercised because the cost (i.e., exercise price) of the next phase of research is likely to be small relative to the potential to resolve significant uncertainty in the technology. Note that the R&D under analysis here occurs prior to the more expensive human Phase I clinical trials (safety trials) and the exorbitantly expensive Phase II/Phase III clinical trials (efficacy trials).

A dominant feature in this framework is an agency problem that the hospital faces. While the hospital provides the early funding for the project, it is the P.I. who spends the funds. But the P.I. has a tremendous incentive to maximize the total funding that his/her research idea will generate. This incentive shows itself in the well-known behavior of P.I.s to divert some portion of the funding to other uses, such as other research efforts, expenditures for larger laboratories (not necessarily required for the project in question) and for additional staff. This behavior comes about for at least two reasons. Firstly, the P.I.'s academic reputation will be made on the quantity and quality of his/her scientific work. Following a path which leads to the fastest commercial development is almost always not the path that provides the P.I. with the greatest academic output. Along a slower development path, with less information in the public domain, the P.I. will have more opportunities for academic publications and the like. The second reason revolves around the significant prestige that accrues to the P.I. as the square footage of his/her laboratory space increases, as the number of scientists and technicians working on his/her projects increases, and as the number of research efforts increase. In many not-for-profit settings, these perquisites are the "coin of the realm" in terms of clout and pecking order issues.

This agency problem is very real. Not-for-profit administrators have been aware of this phenomenon for years, but have been largely unsuccessful in solving it. Advanced degreed scientists typically do not listen to business administrators. Furthermore, entrepreneurs who license early stage technologies also face this phenomenon. This effect has been implicated in the demise of more than one firm.

These considerations lead to a model in the spirit of Glaeser and Schleifer (1998), hereafter GS, in which we assume that the P.I. will maximize a quasi-linear utility function. We will then examine that behavior to evaluate the NPV of the project from the hospital's point of view. In particular, the hospital will wish to determine the appropriate level of project funding.

While our modeling framework looks similar to the GS construction, we are not asking the same questions. GS study circumstances under which a self-interested entrepreneur would choose not-for-profit status versus for-profit status as an organizational structure. In a not-for-profit setting, the entrepreneur may not take profits directly as cash, but as less valuable (to the entrepreneur) perquisites. This non-inurement requirement (i.e., non-distribution constraint) for not-for-profits provides that profits may not be distributed to entities who exercise control over the organization (i.e., officers, directors and trustees)[1].

Our approach is to study the mix of cash and perquisites that the P.I. will take from a project. Note that the P.I. is clearly not in the group of officers, directors and trustees that control the not-for-profit hospital, so that direct payment of cash to the P.I. from any cash proceeds is legal. In fact, in many cases, the not-for-profit hospital must pay cash directly to the P.I. based upon an agreed upon sharing rule when it sells (licenses) the

[1] For a further discussion of this point and additional references, see Patel, Needleman and Zeckhauser (1994).

technology. For example, many academic hospitals operate that way subject to the contract executed with staff physicians[2].

The essence of the agency problem that the hospital faces lies in the fact that it is presumed not to have complete information about the P.I. utility function for perquisites. In the GS model, the utility for perquisites is dV, where V is the dollar amount of perquisites and $0<d<1$. The hospital is assumed not to know d, although we will consider cases in which the hospital uses a probability density function for d, which it might estimate from data on previous projects. In a multi-period setting, the hospital will use a joint density function for perquisite parameters. Further, we will assume the hospital knows that the P.I. will act so as to maximize expected utility, and that both sides know the sharing rules and the selling price function for the technology.

Virtually all recent approaches to the agency problem stem from Jensen and Meckling (1976), in which costless verification of key activities by the agent is not possible. Recent research has addressed establishing appropriate incentive arrangements for agents and/or the implications of the principals' incurring monitoring costs to determine the agent's activities. In our hospital case, neither of these approaches will be productive. Sharing rules between the hospital and the agent are set by contract when the P.I. joins the staff, well before any R&D project is even contemplated. Secondly, we assume that the P.I.'s activities are non-verifiable at any cost. The typical project is basic science R&D for which the P.I. possesses unique and highly intangible capabilities, so who would do the monitoring? As a practical matter, in most cases, the hospital doesn't even try to monitor.

Note that the issue here is the use of the cash funding from the hospital by the P.I. We are not addressing the set of issues arising when the P.I. can intercept future cashflows generated by the project. The hospital, again by contract with the P.I., controls the ultimate licensing of the technology to third parties. For a discussion of the agency problem regarding future cashflows, see Myers (1999).

We do assume that the amount of R&D product at the end of the project is verifiable. It will be necessary for us to argue that, when the P.I. provides results at the end of the project, the amount of funding used for the project can be determined. We will proceed to use this dollar amount of investment as an instrumental variable for R&D output. Then, we will make the selling price for the technology a function of the amount of money applied to the R&D project. In a more comprehensive model, R&D knowledge will be a random variable. See d'Aspremont, et. al., (2000) wherein R&D is modeled as Poisson intensity.

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[2] Also by contract, the P.I. often may not receive stock (in a for-profit buyer of the technology) and get either sponsored research funding or consulting fees from the same entity. It is often argued that this is to protect the public interest by eliminating the opportunity for the P.I. to manipulate research data for a short-term stock windfall. Of course, the hospital can accept equity in the for-profit even if the P.I. gets sponsored research funding or consulting fees. Note, however, that when the hospital sells the stock, the P.I. will get his/her share of the sales price in cash. It is not clear that these restrictions guarantee the objective sought. While the P.I. will not know when nor have any control over when the hospital sells the stock, he/she will surely recognize the (implicit) participation in the hospital's equity and act accordingly.

In this environment, the hospital will want to do the best job it can to estimate the P.I. utility function for perquisites and understand the nature of the errors that these (probabilistic) estimates may induce in its own optimization problem.

The paper is organized as follows:

Section II provides the basic apparatus in a one-period, deterministic model. Optimality conditions are presented for the P.I. and the nature of the hospital's problem is outlined.

Section III introduces the probability functions for perquisite utility and the potential failure of the technology. With the introduction of the density function for perquisite utility, we show that the hospital's NPV maximization problem is tractable. We consider a binomial model for failure in which the selling price as a function of research applied is known conditional upon the success of the research. If the R&D shows that the technology fails, the project ends and the technology is worthless.

Section IV takes the analysis to two periods.

Section V looks at how the hospital can establish the optimal sharing rule between the P.I. and itself.

Section VI is explores a second agency problem that the hospital is likely to face. In addition to diverting cash funding away from the project to perquisites, the P.I. may choose to withhold scientific information for selfish motives. This section studies how that information might ultimately become available to the hospital and potential buyers of the technology, and what the ramifications are for the hospital's management of the project.

Section VII is a brief summary.

SECTION II

In a one-period, deterministic model, how does the P.I. allocate the funding provided between R&D investment and perquisites?

Define

$P(D_1)$ = selling price of the technology at the end of the period

A = % of selling price that goes directly to the P.I.

D = research dollars provided by the hospital

D_1 = dollars applied to the R&D project

D_2 = dollars spent on perquisites

$D = D_1 + D_2$

dD_2 = P.I. utility function for perquisites

$0 < d < 1$

R = interest rate

P is assumed to be concave downward, so that $P' > 0$ and $P'' < 0$. Also, the funds spent on R&D are assumed to be an instrumental variable for the amount of product development, so that P is a function of D_1.

The problem statement for the P.I. is:

$$\text{Max} \quad \left[A * P(D_1) + d * D_2\right]$$

$$\text{s.t.} \quad D = D_1 + D_2$$
$$D_1, D_2 \geq 0$$

$$\underset{D_1}{\text{Max}} \quad \left[A * P(D_1) + d * (D - D_1)\right]$$

$$P'(D_1^*) = \frac{d}{A}$$

As such, the decision rule for the P.I. is:

If $D \leq D_1^*$, then the P.I. chooses $D_1 = D$.
If $D > D_1^*$, then the P.I. chooses $D_1 = D_1^*$.

Recall that the hospital cannot observe d, but knows that $0<d<1$. The hospital wishes to set the level of funding. One approach is for the hospital to solve the P.I. problem with d=1, namely

$$P'(D_1^{**}) = \frac{1}{A}$$

Since $\frac{1}{A} > \frac{d}{A}$, we have $D_1^{**} < D_1^*$. So by providing $D = D_1^{**}$, the hospital can guarantee that 100% of the funding will be invested in the project and not in perquisites. The question then becomes: Is there a way for the Hospital to decide how much more to

invest? It knows that there exists some $D_1 > D_1^{**}$ for which 100% of the funding will be invested in the R&D, but it doesn't know D_1 (because it cannot observe d).

Formally the hospital would like to choose D to maximize the NPV of the project,

$$\text{Max} \quad \frac{[(1-A)*Q(D)]}{1+R} - D$$

where $Q(D) = P(D_1^{***})$; D_1^{***} is the optimal P.I. solution given D. Since Q(D) depends on d, the hospital will be unable to solve this problem.

Throughout this paper we will work with various numerical examples. We will employ logarithmic pricing functions of the following type:

$$P(D_1) = K + K_1 \ln(1 + D_1)$$

where K is a constant representing the value of the technology at time 0 and K_1 is a constant. First order conditions for the P.I. for arbitrary d and for d=1 are, respectively

$$D_1^{*} = \frac{K_1 A}{d} - 1$$

$$D_1^{**} = K_1 A - 1$$

To check the integrity of the model, comparative statics for the basic problem are given in TABLE 1. Recall that D_1^{*} comes from the P.I. expected utility maximization, and would be the optimum funding level if the hospital knew d, the perquisite parameter. D_1^{**} is the optimal funding if the hospital assumes that d=1. Relative to the Base Case in Table 1:

- Scenario #1: comparative static on d (0.7 vs. 0.8); a lower P.I. perquisite parameter would lead to a greater application of funds to the R&D project leading to a higher NPV; D_1^{**} is unchanged since d=1 in both cases.

- Scenario #2: comparative static on A (.20 vs. .25), the P.I.'s share of selling proceeds; a lower A produces less investment by the P.I. (Note that this is the classic Jensen and Meckling (1976) agency situation in which the agent's smaller equity participation leads to higher perquisite consumption, making it more advantageous for the principal to monitor); the hospital's NPV at the optimal funding level, D_1^{*}, falls because R&D investment is lower (even though it takes a larger share of the selling price).

- Scenario #3: comparative static on K_1 (20 vs. 10), the slope coefficient in the pricing function; if R&D is more valuable, it is clearly in the best interest of both agent and principal to apply more dollars to the project.

For our Base Case, CHART 1 shows the hospital's NPV as a function of funding level, D. The NPV is curvi-linear (due to the form of the selling price function, P) up to the P.I. optimum at $D_1^* = 2.125$ and linear beyond that point because all additional funding will go to P.I. perquisites. This curve is not differentiable at D_1^*. The levels of D_1 and D_2 are also plotted against D. Both functions are piecewise linear with inflection point at D_1^*, highlighting that all funding beyond D_1^* goes entirely to perquisite consumption.

SECTION III

Now suppose that the hospital can estimate a probability density function (p.d.f.) for d, p(d). The hospital may observe how the P.I. operated in previous projects and/or look at the spending habits cross-sectionally for various P.I.s. We suspect that the hospital could be able to judge whether the typical P.I. is likely to value perquisites highly (i.e., d close to 1).

How might the hospital determine if d is high? We know, *ceterus paribus*, the higher is d, the lower is the proportion of funding applied to R&D. Suppose we can gather budget and project data for similar projects. Note that at this early R&D stage, many projects consist of animal studies to evaluate toxicology, efficacy and the like. In most cases, the studies will have been done on-site at the hospital. Furthermore, the hospital has detailed information on procurement and housing costs for the animals, costs for supplies and services, etc. So, on an *ex post* basis, the hospital could produce accurate estimates for direct animal study costs. Similarly, invoices would be available for patent prosecution costs and other external services employed. We might argue that the difference between the total budget and these "hard" costs relative to the size of the animal study is correlated with the amount of perquisites taken from the project[3]. Obviously, the total budget will be accounted for with "hard" costs and the various "soft" costs such as allocation of staff time, etc. Allocation of the soft costs leaves plenty of room for discretion on the part of the P.I.

Given p(d), the hospital will wish to maximize NPV by choosing D, the level of funding.

[3] Obviously, this is a stylized discussion. The P.I. who wishes to take perquisites from the project could employ creative ways to include these perquisite costs in the "hard" costs. For example, I have been involved in discussions as to how quickly scalpels will become dull during animal surgeries and dissections, and consequently how many sets of scalpels will be required for a given study size. Not surprisingly, the P.I. will typically argue for the maximum number of instruments. If the study size turns out to be smaller than projected (e.g., animals die prior to being sacrificed), or the physical life of the scalpel can be "stretched", slack will have been introduced into the budget. Since the hospital thinks of the grant to the P.I. as funding without recourse, in all but the most egregious cases, the hospital will not revisit the scalpel issue. Our thrust here is not to explore whether the P.I. may have been dishonest or disingenuous, but rather to suggest that "hard" costs may have to be "sanitized".

$$\text{Max}\left[\frac{(1-A)\int_0^1 Y(D|d)\,p(d)\,dd}{1+R} - D\right]$$

where

$$Y(D \mid d) = \begin{cases} P(D) & \text{if } D \le D_1^*(d) \\ P(D_1^*(d)) & \text{if } D > D_1^*(d) \end{cases}$$

$Y(D \mid d)$ represents the selling price for the technology for any level of funding, D, conditional on perquisite parameter d. So, for any level d, the hospital can compute (by solving the P.I. maximization problem) the amount of money that will go to R&D from any funding level D. $D_1^*(d)$ is the level of R&D investment coming out of the P.I. first order condition. Thus, the integrand in the hospital's NPV equation implicitly contains the optimization that the P.I. would perform.

Note that

$$(1-A)\int_0^1 Y(D|d)\,p(d)\,dd$$

is the expected cashflow to the hospital when the technology is sold at time 1. Again, $Y(D \mid d)$ is not differentiable at $D = D_1^*(d)$. In what follows, we will iteratively search for that level D that maximizes NPV[4].

For purposes of illustration we will assume that p(d) is a discrete p.d.f. and that the selling price function is the logarithmic function described earlier. It is instructive to compute:

1. the project NPV computed by the hospital using its optimal choice D for the funding level, based upon the p.d.f. for d;

2. given this optimal level D, the NPV of the project based upon the <u>actual</u> perquisite parameter of the P.I. (of course, the hospital could not do this calculation);

3. the project NPV and funding level assuming that the hospital knows d;

4. the NPV of the project when the hospital assumes that d=1 and chooses a funding level that guarantees a 100% investment in R&D.

[4] We use the Microsoft EXCEL 97 Solver Add-In for problems of this type throughout this paper. The Add-In employs the Generalized Reduced Gradient (GRG2) non-linear optimization method.

Strategy (1) represents the problem that the hospital will actually solve given the data available to it. Strategy (2) finds the actual NPV to the hospital given the funding level chosen in (1); the difference (2) - (1) measures the error in the NPV that the hospital will report. Strategy (3) represents the solution under complete information to both sides. We will study (1) vs. (3) to explore how the relationship between the assumed p.d.f. for d and the actual perquisite parameter affects the NPV calculation and the amount of over or under investment by the hospital. Strategy (4) assures that there will be no perquisite spending, but will under invest in R&D. It can be thought of as the most conservative strategy.

Table 2 looks at these four strategies for the Base Case one-period model, with A=.25, d=0.8, K=0.005, K_1=10 and R=0.05. The top portion of the Table shows alternative p.d.f.s for d. Panels A, B, and C present densities with constant standard deviation, σ_d, but different means, μ_d. Panel D keeps the mean at 0.8 (the actual d), but makes σ_d = .17, 70% greater than Panel A. Panel E considers a density with μ_d significantly below the actual d=0.8.[5]

Overall, Table 2 demonstrates the intuitive result that the hospital will make the most egregious errors when it works with perquisite parameters that are away from the actual d. In those situations, the hospital's solution procedure will provide too little funding (μ_d>d, Panel B) or will mistakenly calculate that too much of the funding will go to R&D (μ_d<d, Panel E). To see this, look at Table 3 in conjunction with Table 2. Panels A, B and C illustrate the point for p.d.f.s standardized on σ_d . In Panels A and C, there is over funding, but the reported and actual NPV by the hospital are only modestly below the full information optimum. However, Panel B shows that with μ_d>d, there is considerable under funding. The NPV reported by the hospital is 13.1% too low, and the actual NPV is more than 16% below the full information optimum. So, standardizing on σ_d, the data suggest that the largest errors occur when μ_d=.87, farthest away from the actual d=.80. Now consider Panel E where μ_d=.54. There is huge over funding versus the full information optimum (88.2%), a 71% reporting error in NPV, and an actual NPV over 31% below the optimum. In this case, more probability weight is associated with low values for d, which will spur the hospital to provide more funding which will go to perquisites.

Might the volatility in the p.d.f. be a dominant factor in inducing errors by the hospital. Consider Panels A and D in which μ_d = d, but where volatility is 70% greater in D. While over funding occurs with the lower volatility and under funding with the higher volatility, both reported and actual NPV are modestly below the full information optimum.

[5] Numerical results for Panels A and C are the same as a coincidence of magnitudes of the chosen parameters. In each of these cases, the solution chosen by the hospital is identical to the solution with d=0.7. This is a consequence of the slope of the selling price function and the relatively large probabilities for d=0.7. When the hospital computes the expected cashflow, the contribution due to d=0.7 dominates. Parameters could be changed so that the results would not be numerically equal, but the results would be qualitatively the same.

The bottom portion of Table 3 looks at the hospital's performance relative to the conservative Strategy #4. Concentrate on the bottom row. Panels A-D suggest that when μ_d is not far from d, the hospital can find funding levels with slightly higher NPVs than strategy #4, but when μ_d is further away from d, significantly lower NPVs are found. In the case in Panel E, a solution 18% below the conservative strategy #4 strategy is found. Hospital administrators may well decide that over the range of viable parameters and candidate p.d.f.s, Strategy #4 is a reasonable minimum regret strategy.

Now let us allow the possibility that the technology will fail. In particular, let *a* be the probability that the technology will be shown to be worthless (via the application of R&D during the period). The selling price for the technology at time 1, call it P, is

0 if the technology fails (with probability a)

$P(D_1)$ if the technology does not fail (with probability $1-a$)

Further, we assume that both the hospital and the P.I. know *a*.[6] In this setting, we assume that the P.I. attempts to maximize expected utility, so that

$$\text{Max } E\left[A * P + d * D_2\right]$$

$$\text{s.t. } D = D_1 + D_2$$
$$D_1, D_2 \geq 0$$

where E is the expectation operator.

$$\underset{D_1}{\text{Max}} \; [(1-a)*A*P(D_1) + d*(D - D_1)]$$

$$P'(D_1^{*}) = \frac{d}{A(1-a)}$$

Not surprisingly, the higher the probability of failure, the smaller will be the investment in R&D. As before, the hospital may easily solve the P.I. problem with d=1:

$$P'(D_1^{**}) = \frac{1}{A(1-a)}$$

[6] In a more comprehensive model, P would also be a random variable.

At $D = D_1^{**}$, all funds provided will be committed to the research project independent of the actual d. For our assumed logarithmic pricing function,

$$D_1^{*} = \frac{K_1 A(1-a)}{d} - 1$$

$$D_1^{**} = K_1 A(1-a) - 1$$

Working with a p.d.f. for the perquisite parameter, the hospital will perform the following NPV maximization:

$$\underset{D}{\text{Max}} \left[\frac{(1-a)(1-A)\int_0^1 Y(D|d)\, p(d)\, dd}{1+R} - D \right]$$

where $Y(D \mid d)$ is as defined previously. The binomial failure probability introduces the proportionality factor (1-*a*), representing the probability of successful research, in both the P.I. solution and the hospital's NPV problem. However, note that neither the hospital solution nor the P.I. solution will be strictly proportional to the deterministic results because both solutions employ the concave pricing function, $P(D_1)$.

Table 4 provides comparative statics for the basic problem when probabilistic failure is included. Compare Table 4 to Table 1 (e.g., basic problem without failure). Scenarios #1-#3 demonstrate the same qualitative characteristics as Table 1. As expected, both investment levels (D_1^{*}, D_1^{**}) and NPV levels are lower in Table 4 because the probability of failure makes the project less attractive to both the P.I. and the hospital. Scenario #4 shows that a higher failure probability will also reduce (relative to the Base Case) both investment and NPV levels.

Table 5 considers the alternative p.d.f.s for d and is comparable to Table 2. The fundamental result, as in Table 2, is that the hospital makes the most serious errors in both funding and NPV calculation when it incorrectly works with low levels for d (Panel E). The introduction of potential technology failure does not affect the importance of this issue, nor does it change the qualitative characteristics of the problem.

It is also instructive to study the size of the error induced if the hospital mistakenly does not recognize the possibility for failure. For now, suppose that the hospital knows d = 0.8, so as not to introduce effects of the perquisite parameter p.d.f.[7] Using the Base Cases in Tables 1 and 4, we wish to explore the consequences of using the Table 1 solution when the environment is as in Table 4. The hospital will provide funding of D = 2.125, believing that the P.I. will apply all of it to R&D leading to an NPV = 6.02. In fact, the hospital should have provided D = 1.8125 to produce an NPV = 4.84. So the hospital would over fund the project by 17% ((2.125/1.8125)-1). At a 2.125 funding

[7] We make this assumption simply to isolate the effect due to the possibly of failure.

level, the actual NPV = 4.53, so that the hospital would report an NPV that is 33% too high ((6.02/4.53)-1). It is crucial for the hospital to explicitly account for the probability of failure. P.I.s can be very persuasive, so that under estimation of *a* can readily occur.

SECTION IV

In order to extend the analysis to two periods, it will be necessary to:

1. set budget constraints for each period;
2. introduce a P.I. utility function for perquisite consumption in period 2; and
3. posit a selling price function based upon R&D spending applied during each period.

Define

D_1^t = dollars applied to research during period t

D_2^t = dollars applied to perquisites during period t

$D = D_1^1 + D_2^1$ = funding provided during period 1

$C = D_1^2 + D_2^2$ = funding provided during period 2

dD_2^1 = utility of perquisite consumption during period 1

$d'D_2^2$ = utility of perquisite consumption during period 2

$P(D_1^1, D_1^2)$ = selling price of the technology at time 2 as a function of R&D applied during periods 1 and 2

R_1 = interest rate during period 1

R_2 = interest rate during period 2

Regarding $P(D_1^1, D_1^2)$, we assume that the hospital will exercise its option to fund during period 2 unless the technology failed during period 1. If the technology fails during period 1, no funding will occur during the second period. Furthermore, the P.I. is presumed to know this strategy. Also note that if the P.I. has positive time preference for perquisites, then d' < d. We will make this assumption in our numerical examples.

In the deterministic model without failure, the P.I. will solve

$$\text{Max} \quad \left[dD_2^1 + d'D_2^2 + \frac{A * P(D_1^1, D_1^2)}{1 + R_2} \right]$$

$$\text{s.t. } D = D_1^1 + D_2^1$$
$$C = D_1^2 + D_2^2$$
$$D_1^1 , D_2^1 , D_1^2 , D_2^2 \geq 0$$

Note that to allow for a direct comparison to the P.I.'s one period problem, we have discounted the P.I.'s share of the selling proceeds to time 1. Substituting constraints,

$$\text{Max} \quad \left[d(D - D_1^1) + d'(C - D_1^2) + \frac{A * P(D_1^1, D_1^2)}{1 + R_2} \right]$$

$$P_1(D_1^{1*}, D_1^{2*}) = \frac{(1 + R_2)d}{A}$$

$$P_2(D_1^{1*}, D_1^{2*}) = \frac{(1 + R_2)d'}{A}$$

Now consider a selling price function analogous to the single period function[8],

$$P(D_1^1, D_1^2) = K + f(D_1^1) + g(D_1^2)$$

First order conditions are

$$f'(D_1^{1*}) = \frac{(1 + R_2)d}{A}$$

[8] We have chosen this particular additive price function primarily for ease in exposition. A more realistic model would make $g(D_1^2)$, the contribution to selling price due to R&D during the second period, depend upon the amount of R&D during the first period. That is, the larger is the quantity of successful R&D coming from period 1, the more productive R&D will be in period 2. We will make the effect of R&D more explosive in the second period (by choosing a larger slope coefficient in the logarithmic pricing function), but this comes about simply because we were "in the game" during period 1. In many cases, this simpler assumption would lead to lower R&D investment in period 1 by the P.I. The alternative specification for the selling price, $g(D_1^1, D_1^2)$, would lead to non-linear (in D_1^1 and D_1^2) first order conditions in the P.I. maximization. We would solve these optimality conditions numerically and proceed with the analysis.

$$g'(D_1^{2*}) = \frac{(1+R_2)d'}{A}$$

It is also possible to determine funding levels in each period so that 100% of the funding will be applied to R&D. Set d = d' = 1 and choose $D = D_1^{1**}$, $C = D_1^{2**}$ where

$$f'(D_1^{1**}) = \frac{(1+R_2)}{A}$$

$$g'(D_1^{2**}) = \frac{(1+R_2)}{A}$$

For the numerical work that follows, assume that

$$f(D_1^1) = K_1 \ln(1 + D_1^1)$$

$$g(D_1^2) = K_2 \ln(1 + D_1^2)$$

Then

$$D_1^{1*} = \frac{K_1 A}{(1+R_2)d} - 1$$

$$D_1^{2*} = \frac{K_2 A}{(1+R_2)d'} - 1$$

$$D_1^{1**} = \frac{K_1 A}{(1+R_2)} - 1$$

$$D_1^{2**} = \frac{K_2 A}{(1+R_2)} - 1$$

Table 6 provides comparative statics for this two-period deterministic case. Optimum funding amounts under full information, e.g., (D_1^{1*}, D_1^{2*}); funding amounts to guarantee 100% investment under incomplete information about perquisite parameters, e.g., (D_1^{1**}, D_1^{2**}); the NPV at full information funding, e.g., NPV @ (D_1^{1*}, D_1^{2*}); and the NPV at 100% guarantee levels, e.g., NPV @ (D_1^{1**}, D_1^{2**}) are presented. Cases #1 and #5 show that a reduction in either perquisite parameter leads to greater R&D investment in the respective time period to produce a higher (relative to the Base Case) NPV @ (D_1^{1*}, D_1^{2*}). As can be seen from the algebraic equations for (D_1^{1**}, D_1^{2**}), 100% guarantee levels do

not change because these levels are independent of perquisite parameters. Case #2 shows the reduction in all investment levels and resultant reduction in NPVs when the sharing rules are more favorable to the hospital (this is not always the case; later in this paper we will study the optimal sharing rule from the hospital's viewpoint). Case #3 has a more explosive period 1 contribution to selling price, leading to higher D_1^{1*} and D_1^{1**} levels and higher NPVs. Case #4 exhibits the same results for a more steeply sloped period 2 contribution to pricing.

If the hospital is presumed to have a joint p.d.f., p(d,d'), for perquisite parameters, it will choose D and C according to

$$\text{Max} \left[\frac{(1-A)\int_0^1 \int_0^1 Y(D,C \mid d,d')\, p(d,d')\, dd\, dd'}{(1+R_1)(1+R_2)} - D - \frac{C}{1+R_1} \right]$$

$$\text{s.t.} \quad D, C \geq 0$$

where

$$Y(D,C \mid d,d') = \begin{cases} K + f(D) + g(C) & \text{if } D \leq D_1^{1*}(d),\ C \leq D_1^{2*}(d') \\ K + f(D_1^{1*}(d)) + g(C) & \text{if } D \geq D_1^{1*}(d),\ C \leq D_1^{2*}(d') \\ K + f(D) + g(D_1^{2*}(d')) & \text{if } D \leq D_1^{1*}(d),\ C \geq D_1^{2*}(d') \\ K + f(D_1^{1*}(d)) + g(D_1^{2*}(d')) & \text{if } D \geq D_1^{1*}(d),\ C \geq D_1^{2*}(d') \end{cases}$$

Again, note that $Y(D,C \mid d,d')$ subsumes the optimization that the P.I. would execute conditional on perquisite parameters d and d'.

For our illustrations, we will consider a discrete joint p.d.f. for d and d', so the integration in the NPV objective function becomes discrete summation. We then iteratively search for the (D, C) pair that maximizes NPV. Table 7 provides numerical results:

Case #1: The hospital assumes that both d and d' are either high, mid-level, or low. This is a naïve case in which the hospital does not think about d and d' separately. The marginal densities for both d and d' are analogous to Panel C, Table 2 in which the mean μ=.76 falls between our actual d=0.8 and d'=0.6. While over funding occurs in period 1 and under funding in period 2, actual NPV is less than 6% below the full information optimum.

Case #2: In this case, the hospital doesn't distinguish between d and d', but the marginal density means are well below the actual d and d'. Here there is

considerable over funding relative to the optimum (150% for D_1^1; 57% for D_1^2); reported NPV 41% above actual NPV; and actual NPV over 17% below the optimum.

Case #3: The hospital suspects that the P.I. has positive time preference for perquisites, so it assures that the mean of the marginal density for d' is below that of d. The hospital's calculated results are quite close the optimum.

Concerns about Case #2 situations may lead the hospital to embrace the 100% R&D guaranteed funding levels. In our example, this 100% guaranteed funding produces an NPV 20% below the optimum, but there are no reporting errors because we are certain that no perquisites will be taken.

Now let us look at the problem that the P.I. will solve, assuming that the technology can fail in either time period. Let

a = probability that the technology fails during period t=1

b = conditional probability that the technology fails during t=2 (given that it did not fail during t=1)

As before we assume that the P.I. will maximize expected utility, so the P.I. solves[9]

$$\text{Max} \quad \text{E}\left[dD_2^1 + d'D_2^2 + \frac{A * P(D_1^1, D_1^2)}{1 + R_2} \right]$$

$$\text{s.t.} \quad D = D_1^1 + D_2^1$$
$$C = D_1^2 + D_2^2$$
$$D_1^1 , D_2^1 , D_1^2 , D_2^2 \geq 0$$

Further, we assume that the P.I. knows that

1. if the technology fails during t=1, no funding will occur during the second period; and

2. under all circumstances, the hospital will wait until t=2 to sell the technology.

Let us illustrate using our standard selling price function,

$$P(D_1^1, D_1^2) = K + f(D_1^1) + g(D_1^2)$$

[9] This is the problem that the P.I. will solve even knowing that the hospital will make its funding commitment sequentially, deciding on C after observing what happens at t=1 (that is, if the technology fails at t=1, it will set C = 0).

The terms in the P.I.'s expected utility objective function are

TERM	SITUATION	CONTRIBUTION TO EXPECTED UTILITY
X	Failure @ t=1	adD_2^1
Y	Failure @ t=2	$(1-a)\,b\left[dD_2^1 + d'D_2^2\right]$
Z	No failure	$(1-a)(1-b)\left[dD_2^1 + d'D_2^2 + (\frac{A}{1+R_2})(K + f(D_1^1) + g(D_1^2))\right]$

So the P.I. will solve

$$\text{Max} \quad X + Y + Z$$

$$\text{s.t.} \quad D = D_1^1 + D_2^1$$
$$C = D_1^2 + D_2^2$$
$$D_1^1 \,,\, D_2^1 \,,\, D_1^2 \,,\, D_2^2 \geq 0$$

Substituting for D_1^2 and D_2^2 and differentiating,

$$\frac{\partial}{\partial D_1^1}: \qquad -ad - (1-a)\,bd + (1-a)(1-b)\{-d + \frac{A}{1+R_2} f'(D_1^1)\}$$

$$\frac{\partial}{\partial D_1^2}: \qquad -(1-a)\,bd' + (1-a)(1-b)\{-d' + \frac{A}{1+R_2} g'(D_1^2)\}$$

First order conditions are

$$f'(D_1^{1*}) = \frac{d\,(1+R_2)}{(1-a)(1-b)\,A}$$

$$g'(D_1^{2*}) = \frac{d'(1+R_2)}{(1-b)\,A}$$

For the logarithmic price functions, we have

$$D_1^{1*} = \frac{K_1\,(1-a)(1-b)\,A}{d\,(1+R_2)} - 1$$

$$D_1^{2*} = \frac{K_2 (1-b) A}{d'(1+R_2)} - 1$$

Table 8 provides comparative statics for the P.I. maximization problem for the two-period model with failure. After introduction of failure probabilities *a* and *b*, the Base Case assumptions are identical to Table 6 (e.g., the two-period deterministic model). Not surprisingly, potential failure leads to both lower investment/funding levels, optimum and 100% guaranteed, and lower NPVs. Cases #1 - #5 in Table 8 are directly comparable to Table 6, with identical qualitative results. In these cases, the introduction of failure lowers the magnitudes but does not change the structural relationships in the problem. Cases #6 and #7 look at the failure probabilities directly. In case #6, in which the period 1 failure probability is increased, observe lower investment levels in period 1, but no change (relative to the Base Case) in period 2 investment levels. This occurs because, conditional upon proceeding to period 2, the probability of failure in period 1 is irrelevant. In case #7, in which the period 2 failure probability is increased, note that the period 1 and period 2 investment levels fall relative to the Base Case. Even in period 1, the P.I. will account for the fact that his/her expected payoff share of the sale proceeds will be lower due to the greater failure possibility in period 2. This accounting in period 1 takes the form of a smaller investment, or equivalently, a greater proclivity to use funding for perquisites.

When the hospital works with a joint p.d.f., p(d,d'), it will attempt to maximize NPV by choosing D and C. It knows that the P.I. will do the above calculations. What are the expected cashflows to the hospital?

Time	Description	Expected cashflow
0	Cash outflow	D
1	Expected cash outflow	$(1-a)C$
2	Expected cash inflow	$(1-A)(1-a)(1-b)\int_0^1\int_0^1 Y(D,C\|d,d')\,p(d,d')\,dd\,dd'$

$Y(D,C \mid d,d')$ is as defined earlier with $D_1^{1*}(d)$ and $D_1^{2*}(d')$ calculated using the P.I. formulation. Thus, the formal statement of the hospital's problem is

$$\underset{D,C}{\text{Max}} \left[\frac{(1-A)(1-a)(1-b)\int_0^1\int_0^1 Y(D,C \mid d,d')\,p(d,d')\,dd\,dd'}{(1+R_1)(1+R_2)} - D - \frac{(1-a)C}{1+R_1} \right]$$

$$\text{s.t.} \quad D, C \geq 0$$

Table 9 presents (D,C) solutions for the same three perquisite p.d.f.s as in Table 7. For the same reasons that the P.I. applies less to R&D, the hospital will choose to provide less funding in both periods because of the possibility of failure. However, the introduction of failure does not change the character of the errors that the hospital will make. As in Table 7, the hospital makes the largest errors when it attributes large probability to perquisite parameters below the actual levels (see Case #2 in Table 9).

SECTION V

In the analysis to this point, we have assumed that the sharing rule for the hospital and the P.I. was fixed exogenously. We assumed that the parameter A was set by contract when the P.I. took employment at the hospital.

How might the hospital determine the appropriate level for A, the P.I.'s equity participation in the project? For specific projects of the type presented here, the hospital could solve the NPV maximization problem with A as an additional decision variable. As such, the hospital maximizes NPV by simultaneously choosing funding levels and A.

Consider the one-period Base Cases from Tables 1 and 4 and the two-period Base Cases from Tables 6 and 8. For illustration, assume the full information scenario in which the hospital is presumed to know the P.I. perquisite parameters. Table 10 presents optimal solutions when the hospital maximizes NPV by choosing both funding levels and A. Table 10 shows that, for our standard models, the optimal A level ranges between .232 and .285. Since we chose A=.25 in our earlier illustrations, it is not surprising to find the resultant funding levels and NPVs very close to the Base Case levels.

Without the benefit of these analytical results, it might be tempting for the hospital to choose a much lower level for A.[10] The thinking would be that the P.I. is grateful for R&D financing and that a nominal equity participation for the P.I. is sufficient. Our illustrations suggest otherwise, namely that the hospital could induce the P.I. to allocate more funding to R&D by setting A higher. Furthermore, even after paying the P.I. a larger share of the sales price proceeds, the NPV to the hospital is higher.

Now consider our one-period model both with and without failure with A set at a nominal level 0.05. In either case, the P.I. would have to have a perquisite parameter $d\lambda 0.4$ or below to allocate any of the funding to R&D. To get NPV levels similar to the reported Base Cases in Tables 1 and 4, the perquisite parameter would have to be as low as 0.2. The two-period results are similar. However, for reasons discussed earlier, including that fact that the P.I. is likely to have considerable income sources apart from the project, we should expect the P.I. perquisite parameters to be high.

For completeness, similar results are presented for scenarios in which the hospital works with a p.d.f. for perquisite parameters. Table 11 shows the optimal funding and sharing

[10] For example, I am aware of an actual case in which A was set at approximately 0.05.

rule, A, for the one-period model without failure; Table 12 introduces failure; Table 13 provides results for two-periods without failure; and Table 14 gives two-period results with failure. Also, as in the one-period cases, if A is set at 0.05, perquisite parameters would have to be very low to induce R&D investment by the P.I. and to produce NPVs close to the Base Case NPVs.

SECTION VI

The purpose of this section is to explore a second agency problem that is faced by the hospital. In addition to diverting research funds away from the project for perquisites, the P.I. is generally reluctant to make all relevant information about the technology available. At any point in time, there is information that is available in the public domain (e.g., published papers, issued patents), and other information that the P.I. is prepared to release under confidentiality. There is a second category of information, possibly including unpublished manuscripts and in-progress animal studies which the P.I. may not make available, even under confidentiality. The P.I. may genuinely believe that the material is too preliminary for release, or may wish to exploit the information further for academic and career motives, or may view this information as a mechanism to maintain control of the project.

Borrowing from the incomplete contracts literature, we call the first category of observable information verifiable content, and the second unobservable component non-verifiable content.

Define

C_1^t = verifiable content at time t

C_2^t = non-verifiable content at time t

Consider a variant of our simplest one-period model in which the selling price, P, depends upon the level of verifiable content. Standing at t=0, there is some level of verifiable content, C_1^0, and some level of non-verifiable content, C_2^0. C_2^0 is known to the P.I., but neither the hospital nor potential licensees of the technology know C_2^0. Furthermore, we assume that the non-verifiable content will become verifiable with the passage of time, either because the relevant information gets published or because the P.I. is pressured to release the information to obtain the next round of funding.[11] For our illustration, suppose that C_2^0 becomes verifiable at t=1. Therefore, at t=0, the technology

[11] This second effect is a key motivation for the hospital to provide sequential funding as opposed to giving the P.I. a large lump sum funding at t=0. Since the hospital does not expect a rebate from the P.I. under any circumstances, sequential funding allows the hospital to both stop funding if the technology fails and obtain otherwise non-verifiable information from the P.I. Sequential funding can be thought of as a mechanism to mitigate agency costs associated with non-verifiable content.

would sell for $P(C_1^0)$. At t=1, with no additional investment applied to R&D, the selling price would be $P(C_1^0 + C_2^0)$, because the non-verifiable content from t=0 would become verifiable at t=1.

In this model, the hospital has three mutually exclusive options:

1. Sell the technology at t=0 for $P(C_1^0)$;

2. Wait one period, do not provide additional funding, and sell at t=1 for $P(C_1^0 + C_2^0)$;

3. Fund the project during the period and sell at t=1.

Under alternative 3., the P.I. behaves according to

$$\text{Max} \quad \left[A * P(C_1^0 + C_2^0 + BD_1) + d * D_2\right]$$

$$\text{s.t.} \quad D = D_1 + D_2$$
$$D_1, D_2 \geq 0$$

where B is the percentage of the investment level, D_1, that is verifiable at time 1 ($(1\text{-}B)D_1$ is non-verifiable). All other variables are defined as in Section II. Both types of agency costs are seen in the P.I. objective function. D_2 captures the diversion of funding to perquisites as described in Sections I - IV. $BD_1 = C_1^1$ represents that % of research applied that is, in fact, verifiable. Given B<1[12], the P.I. will choose D_1 so that

$$P'(C_1^0 + C_2^0 + BD_1^*) = \frac{d}{AB}$$

So, from the hospital's viewpoint, project NPV under each scenario is:

SCENARIO	HOSPITAL NPV
1. Sell at t=0	$(1-A)*P(C_1^0)$
2. Wait, but do not fund	$\frac{(1-A)*P(C_1^0+C_2^0)}{1+R}$
3. Wait and fund	$\frac{(1-A)*P(C_1^0+C_2^0+BD_1^*)}{1+R} - D$

[12] B would almost surely be endogenous to this problem. That is, the P.I. would maximize by choosing both B and D_1. However, in this simple model, we have not provided a complete modeling of this second agency problem. In this incomplete setting, the optimal B would be 1 because we have not modeled the advantages to the P.I. of withholding information.

A sufficient condition for the hospital not to sell the technology at t=0 is to show that 2. > 1.,[13]

$$(1-A)*P(C_1^0) < \frac{(1-A)*P(C_1^0+C_2^0)}{1+R}$$

$$P(C_1^0+C_2^0) > (1+R)P(C_1^0)$$

The larger is C_2^0 relative to C_1^0 and the steeper is P, the more likely the inequality will hold. Since we are dealing with very early stage projects, C_2^0 is likely to be large because virtually all of the R&D will be incomplete. P is also likely to be in its steepest region because there is relatively little accumulated verifiable content.

Should the hospital fund the project with D dollars during the period, that is, is 3. > 2.?

$$\frac{(1-A)*P(C_1^0+C_2^0+BD_1^*)}{1+R} - D > \frac{(1-A)*P(C_1^0+C_2^0)}{1+R}$$

Defining Z = $C_1^0 + C_2^0$ and rearranging terms, we have

$$P(Z+BD_1^*) > \frac{D(1+R)}{(1-A)} + P(Z)$$

It can also be shown that[14]

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[13] In the discussion that follows, we are implicitly assuming that $C_2^0 > 0$. If $C_2^0 < 0$, the P.I. faces several interesting ethical questions. What should the P.I. do if the hospital elects to sell at t=0 for $P(C_1^0)$, knowing that the value is less than $P(C_1^0)$? Should the P.I. accept incremental funding without releasing C_2^0?

[14] To see this, consider the tangent line to P at the point $(Z+BD_1^*)$,

$$y = P(Z+BD_1^*) + P'(Z+BD_1^*)*(x-(Z+BD_1^*))$$

Since P is concave, any point on P must be below the tangent, in particular point Z, so

$$P(Z) + (BD_1^*)*P'(Z+BD_1^*) < P(Z+BD_1^*)$$

Substituting for $P'(Z+BD_1^*)$ from the P.I. first order condition, we have

$$P(Z) + \frac{dD_1^*}{A} < P(Z+BD_1^*)$$

$$P(Z)+\frac{dD_1^*}{A} < P(Z+BD_1^*)$$

Using these two inequalities, a sufficient condition for incremental funding during the period is

$$P(Z)+\frac{dD_1^*}{A}>\frac{D(1+R)}{(1-A)}+P(Z)$$

$$\frac{D_1^*}{D}>\frac{(1+R)A}{d(1-A)}$$

But *d* is likely to be large relative to A and R; for our Base Case with A=.25, *d*=0.8, and R=0.05, $\frac{(1+R)A}{(1-A)d}=0.44$. So, in order for this last inequality to be violated and therefore for the hospital to refuse incremental funding, the hospital would have to do a particularly poor job in estimating the P.I. perquisite parameter. In this particular case, the hospital would have to choose a funding level, D, so that 56% of that funding was diverted to perquisites in order to violate the inequality condition. For example, none of the scenarios in Tables 2 and 3 would violate the condition.

One might mistakenly argue that, by induction, this modeling suggests that the hospital should never sell the technology. That is, in order to benefit from the non-verifiable content that will become verifiable within one period, might the hospital always run the project for one more period? Of course, at some point in time, the accumulated verifiable content, call it $\overline{C}$, will be sufficiently large so that no positive D_1^* exists. Recall that, in this case, D_1^* must satisfy the P.I. first order condition

$$P'(\overline{C}+BD_1^*)=\frac{d}{AB}$$

But since P is concave downward, there will be a point when $\overline{C}$ is large enough so that no $D_1^* > 0$ works, so that the P.I. will invest nothing in R&D. As such, a time period will elapse in which no new verifiable or non-verifiable content will be generated. Although some previously non-verifiable content may become verifiable during the period, no new funding will be applied to the project. Therefore, the latest point at which it could be optimal for the hospital to sell the technology would be when this last existing non-verifiable content becomes verifiable. Nothing would be gained by waiting longer.

SECTION VII

The purpose of this paper is to study the classic agent/principal relationship in the context of an R&D project inside a not-for-profit hospital. The hospital (principal) funds a P.I. (agent) to undertake R&D on a commercially promising technology. We discuss why the P.I. has the motive and ample opportunity to redirect some portion of the funding to non-productive (from the hospital's point of view) perquisites. How should the hospital act in this setting?

Two classic approaches to the agent/principal problem concern themselves with monitoring and monitoring costs by the principal and establishing schemes for the agent so as to maximize the interests of the principal.[15] In this paper we consider neither approach, but rather concentrate on decision making by the hospital when it has either full, limited or virtually no information about the P.I.'s utility function. We consider single and multi-period models with and without the possibility of failure of the technology. Key results include:

- When the hospital has full information about the P.I.'s utility function, it can set funding levels so that the P.I. will apply all funding to investment in R&D. Since at those levels the hospital will maximize NPV, there is no real agency problem.

- When the hospital has no information about the P.I.'s utility for perquisites, it can still determine a non-trivial funding level so that 100% of the funding would be applied to R&D. However, the funding level does not maximize NPV, and there are almost surely higher funding levels which would be fully invested by the P.I. and lead to a higher NPV for the hospital.

- If the hospital is prepared to posit or estimate a probability density function for the P.I.'s utility perquisite parameters, a solution procedure is provided which finds funding levels to maximize NPV. We then compare these results with the full information optimum (presumed unknown to the hospital) and the 100% guaranteed funding level. We show that the hospital will make the largest errors when it's p.d.f. for perquisites is biased low.

We also demonstrate how the how the hospital might establish the amount of equity participation in the project for the P.I.

What if the P.I. chooses to withhold scientific information for selfish motives? The hospital will be subject to a second agency problem. A modeling environment is provided to look at this phenomenon.

[15] Note that in our setting, the proportional sharing rule between the P.I. and the hospital for the proceeds from the eventual sale of the technology is essentially equity sharing. Our results are consistent with the notion that an all equity compensation package is not sufficient to eliminate the agent/principal problem. In our cases, the agent may still use some of the funding for non-productive perquisites.

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TABLE 1

COMPARATIVE STATICS FOR ONE-PERIOD DETERMINISTIC MODEL

	BASE CASE	SCENARIO #1	SCENARIO #2	SCENARIO #3
K	.005	.005	.005	.005
K_1	10	10	10	***20***
A	.25	.25	***.20***	.25
d	0.8	***0.7***	0.8	0.8
R	0.05	0.05	0.05	0.05
D_1^*	2.13	2.57	1.50	5.25
D_1^{**}	1.50	1.50	1.00	4.00
$NPV@D_1^*$	6.02	6.52	5.49	20.93
$NPV@D_1^{**}$	5.05	5.05	4.28	19.00

where:

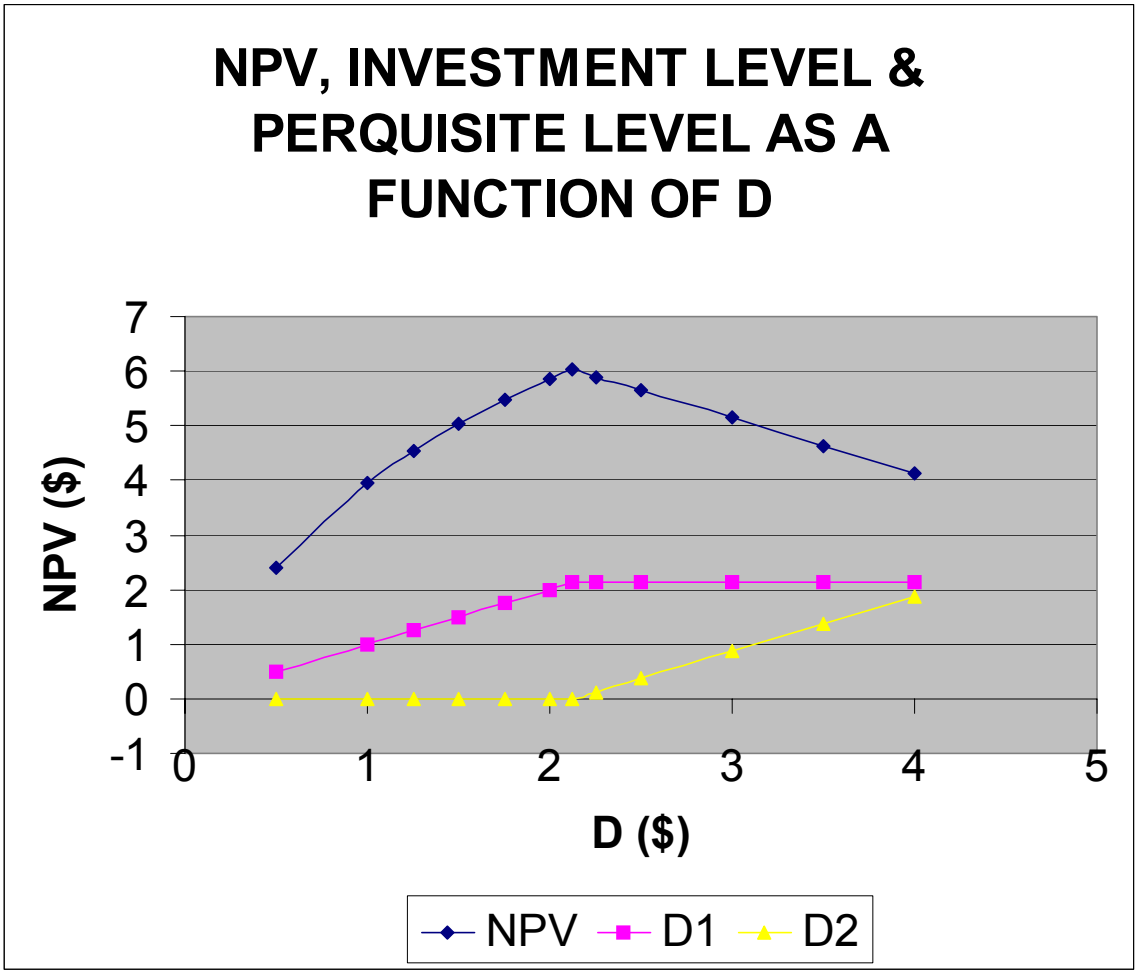
Selling price @ time 1 = $K + K_1 \ln(1+D_1)$

D_1^* = optimal hospital investment

D_1^{**} = hospital funding to guarantee 100% investment in the project, assuming that d is unobservable

CHART 1

BASIC PROPERTIES FOR ONE-PERIOD DETERMINISTIC MODEL



where:

D_1 = investment in R&D

D_2 = perquisite consumption

$D = D_1 + D_2$

TABLE 2

ALTERNATIVE STRATEGIES FOR ONE-PERIOD MODEL WITH P.D.F. FOR d

	A		B		C		D		E	
P.D.F	d	prob	d	prob	d	prob	d	prob	d	prob
	.9	.5	.9	.9	.9	.3	.9	.75	.9	.1
	.8	0	.8	0	.8	0	.8	0	.8	0
	.7	.5	.7	0	.7	.675	.7	0	.7	0
	.6	0	.6	.07	.6	0	.6	0	.6	0
	.5	0	.5	.03	.5	.025	.5	.25	.5	.9
μ_d	.80		.87		.76		.80		.54	
σ_d	.10		.10		.10		.17		.12	
#1										
D		2.57		1.50		2.57		1.78		4.00
NPV		5.63		4.39		5.99		5.52		7.08
#2										
D		2.57		1.50		2.57		1.78		4.00
NPV		5.57		5.05		5.57		5.53		4.14

The underlying model is our Base Case with A=.25, d=0.8, K=0.005, K_1=10, and R=0.05. Strategy #3 has D=2.125 and NPV=6.02 for all p.d.f s; Strategy #4 has D=1.5 and NPV=5.05 for all p.d.f s.

TABLE 3

PERCENTAGE ERRORS FOR ALTERNATIVE STRATEGIES IN ONE-PERIOD MODEL WITH P.D.F. FOR d

P.D.F	A	B	C	D	E
μ_d	.80	.87	.76	.80	.54
σ_d	.10	.10	.10	.17	.12
Over investment in D vs. Strategy #3[16]	20.9%	-29.4%	20.9%	-16.2%	88.2%
Overestimate of NPV vs. Strategy #2[17]	1.1%	-13.1%	7.5%	-0.2%	71.0%
Overestimate of NPV vs. Strategy #3[18]	-6.5%	-27.1%	-0.4%	-8.3%	17.6%
NPV – Strategy #2 vs. Strategy #3	-7.5%	-16.1%	-7.5%	-0.2%	-31.2%
Over investment in D vs. Strategy #4	71.3%	0.0%	71.3%	18.7%	166.6%
Reported NPV vs. Strategy #4	11.5%	-13.1%	18.6%	9.3%	40.2%
Actual NPV vs. Strategy #4	10.3%	0.0%	10.3%	9.5%	-18.0%

The underlying model is our Base Case with A=.25, d=0.8, K=0.005, K_1=10, and R=0.05. Strategy #3 has D=2.125 and NPV=6.02 for all p.d.f.s; Strategy #4 has D=1.5 and NPV=5.05 for all p.d.f s.

[16] Over investment relative to funding with full information (i.e., Strategy #3).
[17] Relative to the actual NPV with the chosen funding level (i.e., Strategy #2).
[18] Relative to the NPV with full information (i.e., Strategy #3).

TABLE 4

COMPARATIVE STATICS FOR ONE-PERIOD MODEL WITH FAILURE

	BASE CASE	SCENARIO #1	SCENARIO #2	SCENARIO #3	SCENARIO #4
a	0.1	0.1	0.1	0.1	***0.2***
K	.005	.005	.005	.005	.005
K1	10	10	10	***20***	10
A	.25	.25	***.20***	.25	.25
d	0.8	***0.7***	0.8	0.8	0.8
R	0.05	0.05	0.05	0.05	0.05
D_1^*	1.81	2.21	1.25	4.63	1.50
D_1^{**}	1.25	1.25	0.80	3.50	1.00
NPV@ D_1^*	4.84	5.29	4.31	17.59	3.74
NPV@ D_1^{**}	3.97	3.97	3.23	15.84	2.96

where:

a = failure probability

Selling price @ time 1 = $K + K_1 \ln(1 + D_1)$

D_1^* = optimal hospital investment

D_1^{**} = hospital funding to guarantee 100% investment in the project, assuming that d is unobservable

TABLE 5

ALTERNATIVE STRATEGIES FOR ONE-PERIOD MODEL WITH P.D.F. FOR d WITH FAILURE[19]

	A		B		C		D		E	
P.D.F	d	prob	d	prob	d	prob	d	prob	d	prob
	.9	.5	.9	.9	.9	.3	.9	.75	.9	.1
	.8	0	.8	0	.8	0	.8	0	.8	0
	.7	.5	.7	0	.7	.675	.7	0	.7	0
	.6	0	.6	.07	.6	0	.6	0	.6	0
	.5	0	.5	.03	.5	.025	.5	.25	.5	.9
μ_d	.80		.87		.76		.80		.54	
σ_d	.10		.10		.10		.17		.12	
#1										
D		2.21		1.50		2.21		1.50		3.50
NPV		4.49		4.39		4.81		4.39		5.79
#2										
D		2.21		1.50		2.21		1.50		3.50
NPV		4.44		4.39		4.44		4.39		3.15

The underlying model is our Base Case with a=0.1, A=.25, d=0.8, K=0.005, K_1=10, and R=0.05. Strategy #3 has D=1.8125 and NPV=4.84 for all p.d.f s; Strategy #4 has D=1.25 and NPV=3.97 for all p.d.f s.

[19] Panels A and C lead to an investment level equal to that with d = 0.7; Panels B and D produce an investment level identical to the solution with d = 0.9.

TABLE 6

COMPARATIVE STATICS FOR TWO-PERIOD DETERMINISTIC MODEL

	BASE CASE	CASE #1	CASE #2	CASE #3	CASE #4	CASE #5
K	.005	.005	.005	.005	.005	.005
K_1	10	10	10	***15***	10	10
K_2	20	20	20	20	***25***	20
A	.25	.25	***.20***	.25	.25	.25
d	0.8	***0.7***	0.8	0.8	0.8	0.8
d'	0.6	0.6	0.6	0.6	0.6	***0.5***
R_1	0.05	0.05	0.05	0.05	0.05	0.05
R_2	0.05	0.05	0.05	0.05	0.05	0.05
D_1^{1*}	1.98	2.40	1.38	3.46	1.98	1.98
D_1^{2*}	6.94	6.94	5.35	6.94	8.92	8.52
D_1^{1**}	1.38	1.38	0.90	2.57	1.38	1.38
D_1^{2**}	3.76	3.76	2.81	3.76	4.95	3.76
NPV @ (D_1^{1*}, D_1^{2*})	27.02	27.51	26.65	33.38	35.97	27.99
NPV @ (D_1^{1**}, D_1^{2**})	22.17	22.17	20.51	28.07	30.14	22.17

where:

(D_1^{1*}, D_1^{2*}) = optimum P.I. R&D investment levels in periods 1 and 2

(D_1^{1**}, D_1^{2**}) = 100% guaranteed R&D investment levels

TABLE 7

ALTERNATIVE STRATEGIES FOR TWO-PERIOD MODEL WITH P.D.F. FOR (d, d')

CASE		#1			#2			#3	
P.D.F	d	d'	prob	d	d'	prob	d	d'	prob
	.9	.9	.3	.9	.9	0	.9	.8	.3
	.8	.8	0	.8	.8	0	.8	.7	0
	.7	.7	.675	.7	.7	0	.7	.6	.675
	.6	.6	0	.5	.5	.1	.6	.5	0
	.5	.5	.025	.4	.4	.9	.5	.4	.025
D			2.40			4.95			2.40
C			5.80			10.88			6.94
REPORTED NPV			24.95			30.04			25.82
ACTUAL NPV			25.58			20.29			26.60
NPV @ (D_1^{1*}, D_1^{2*})			27.02			27.02			27.02
NPV @ (D_1^{1**}, D_1^{2**})			22.17			22.17			22.17

TABLE 8

COMPARATIVE STATICS FOR TWO-PERIOD MODEL WITH FAILURE

	BASE CASE	CASE #1	CASE #2	CASE #3	CASE #4	CASE #5	CASE #6	CASE #7
a	0.1	0.1	0.1	0.1	0.1	0.1	***0.15***	0.1
b	0.075	0.075	0.075	0.075	0.075	0.075	0.075	***0.1***
K	.005	.005	.005	.005	.005	.005	.005	.005
K_1	10	10	10	***15***	10	10	10	10
K_2	20	20	20	20	***25***	20	20	20
A	.25	.25	***.20***	.25	.25	.25	.25	.25
d	0.8	***0.7***	0.8	0.8	0.8	0.8	0.8	0.8
d'	0.6	0.6	0.6	0.6	0.6	***0.5***	0.6	0.6
R_1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
R_2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
D_1^{1*}	1.48	1.83	0.98	2.72	1.48	1.48	1.34	1.41
D_1^{2*}	6.34	6.34	4.87	6.34	8.18	7.81	6.34	6.14
D_1^{1**}	0.98	0.98	0.59	1.97	0.98	0.98	0.87	0.93
D_1^{2**}	3.40	3.40	2.52	3.40	4.51	3.40	3.40	3.29
NPV @ (D_1^{1*}, D_1^{2*})	20.81	21.21	20.37	25.58	28.04	21.61	19.40	19.84
NPV @ (D_1^{1**}, D_1^{2**})	16.77	16.77	15.26	21.16	23.18	16.77	15.59	15.91

TABLE 9

ALTERNATIVE STRATEGIES FOR TWO-PERIOD MODEL WITH P.D.F. FOR (d, d') WITH FAILURE

CASE		#1			#2			#3	
P.D.F	d	d'	prob	d	d'	prob	d	d'	prob
	.9	.9	.3	.9	.9	0	.9	.8	.3
	.8	.8	0	.8	.8	0	.8	.7	0
	.7	.7	.675	.7	.7	0	.7	.6	.675
	.6	.6	0	.5	.5	.1	.6	.5	0
	.5	.5	.025	.4	.4	.9	.5	.4	.025
D			1.83			3.95			1.83
C			5.29			10.01			6.34
REPORTED NPV			19.08			23.32			19.81
ACTUAL NPV			19.57			15.17			20.45
NPV @ (D_1^{1*}, D_1^{2*})			20.81			20.81			20.81
NPV @ (D_1^{1**}, D_1^{2**})			16.77			16.77			16.77

TABLE 10

JOINT DETERMINATION OF A AND FUNDING LEVELS

	One-period Without failure		One-period With failure		Two-period Without failure		Two-period With failure	
A	.250	.280	.250	.285	.250	.232	.250	.241
D_1^*	2.13	2.51	1.81	2.21				
NPV @ D_1^*	6.02	6.09	4.84	4.94				
D_1^{1*}					1.98	1.77	1.48	1.39
D_1^{2*}					6.94	6.38	6.34	6.08
NPV @ (D_1^{1*}, D_1^{2*})					27.02	27.08	20.81	20.83

TABLE 11

ALTERNATIVE STRATEGIES FOR ONE-PERIOD MODEL WITH P.D.F. FOR d
JOINT DETERMINATION OF A AND FUNDING LEVELS

	A		B		C		D		E	
P.D.F	d	prob	d	prob	d	prob	d	prob	d	prob
	.9	.5	.9	.9	.9	.3	.9	.75	.9	.1
	.8	0	.8	0	.8	0	.8	0	.8	0
	.7	.5	.7	0	.7	.675	.7	0	.7	0
	.6	0	.6	.07	.6	0	.6	0	.6	0
	.5	0	.5	.03	.5	.025	.5	.25	.5	.9
μ_d	.80		.87		.76		.80		.54	
σ_d	.10		.10		.10		.17		.12	
A		.294		.297		.241		.296		.172
#1										
D		2.36		2.30		2.44		2.29		2.45
NPV		5.70		5.70		5.95		5.70		6.85
#2										
D		2.36		2.30		2.44		2.29		2.45
NPV		5.79		5.70		5.53		5.70		3.60
#3										
D		2.68		2.72		2.01		2.70		1.15
NPV		6.08		6.07		5.96		6.08		4.90
#4										
D		1.94		1.97		1.41		1.96		0.72
NPV		5.32		5.32		4.95		5.32		3.57

where:

Strategy #1: reported NPV
Strategy #2: actual NPV, given hospital solution
Strategy #3: full information solution
Strategy #4: guaranteed 100% investment solution

TABLE 12

ALTERNATIVE STRATEGIES FOR ONE-PERIOD MODEL WITH P.D.F. FOR d WITH FAILURE
JOINT DETERMINATION OF A AND FUNDING LEVELS

	A		B		C		D		E	
P.D.F	d	prob	d	prob	d	prob	d	prob	d	prob
	.9	.5	.9	.9	.9	.3	.9	.75	.9	.1
	.8	0	.8	0	.8	0	.8	0	.8	0
	.7	.5	.7	0	.7	.675	.7	0	.7	0
	.6	0	.6	.07	.6	0	.6	0	.6	0
	.5	0	.5	.03	.5	.025	.5	.25	.5	.9
μ_d	.80		.87		.76		.80		.54	
σ_d	.10		.10		.10		.17		.12	
A		.308		.305		.249		.305		.178
#1										
D		2.09		2.05		2.21		2.05		2.20
NPV		4.60		4.60		4.81		4.60		5.59
#2										
D		2.09		2.05		2.21		2.05		2.20
NPV		4.60		4.60		4.43		4.60		2.69
#3										
D		2.47		2.43		1.81		2.43		1.00
NPV		4.91		4.92		4.83		4.92		3.89
#4										
D		1.77		1.74		1.24		1.74		0.60
NPV		4.23		4.27		3.96		4.27		2.72

where:

Strategy #1: reported NPV
Strategy #2: actual NPV, given hospital solution
Strategy #3: full information solution
Strategy #4: guaranteed 100% investment solution

TABLE 13

ALTERNATIVE STRATEGIES FOR TWO-PERIOD MODEL WITH P.D.F. FOR (d, d')
JOINT DETERMINATION OF A AND FUNDING LEVELS

CASE		#1			#2			#3	
P.D.F	d	d'	prob	d	d'	prob	d	d'	prob
	.9	.9	.3	.9	.9	0	.9	.8	.3
	.8	.8	0	.8	.8	0	.8	.7	0
	.7	.7	.675	.7	.7	0	.7	.6	.675
	.6	.6	0	.5	.5	.1	.6	.5	0
	.5	.5	.025	.4	.4	.9	.5	.4	.025
A			.247			.183			.233
D			2.36			3.36			2.17
C			5.73			7.73			6.40
REPORTED NPV			24.95			31.80			25.88
ACTUAL NPV			25.59			21.15			26.68
D_1^{1*}			1.94			1.18			1.78
D_1^{2*}			6.85			4.82			6.40
NPV @ (D_1^{1*}, D_1^{2*})			27.04			26.10			27.08
D_1^{1**}			1.35			0.75			1.22
D_1^{2**}			3.71			2.49			3.44
NPV @ (D_1^{1**}, D_1^{2**})			22.12			16.61			21.79

TABLE 14

ALTERNATIVE STRATEGIES FOR TWO-PERIOD MODEL WITH P.D.F. FOR (d, d') WITH FAILURE
JOINT DETERMINATION OF A AND FUNDING LEVELS

CASE		#1			#2			#3	
P.D.F	d	d'	prob	d	d'	prob	d	d'	prob
	.9	.9	.3	.9	.9	0	.9	.8	.3
	.8	.8	0	.8	.8	0	.8	.7	0
	.7	.7	.675	.7	.7	0	.7	.6	.675
	.6	.6	0	.5	.5	.1	.6	.5	0
	.5	.5	.025	.4	.4	.9	.5	.4	.025
A			.250			.188			.245
D			1.83			2.72			1.77
C			5.30			7.27			6.18
REPORTED NPV			19.08			24.61			19.82
ACTUAL NPV			19.61			15.80			20.48
D_1^{1*}			1.48			0.86			1.42
D_1^{2*}			6.34			4.52			6.18
NPV @ (D_1^{1*}, D_1^{2*})			20.81			20.03			20.82
D_1^{1**}			0.98			0.49			0.94
D_1^{2**}			3.41			2.31			3.31
NPV @ (D_1^{1**}, D_1^{2**})			16.77			14.66			16.67